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## Supply chain integration for low-carbon buildings: A critical interdisciplinary review

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# Supply chain integration for low-carbon buildings: A critical interdisciplinary review

## 1. INTRODUCTION

Bolstered in part by national climate policy, as well as supranational requirements such as standards and Directives, the global buildings sector is undergoing a far-reaching transformation to low-carbon infrastructure. As an example, the United Kingdom (UK) has adopted a target of reducing greenhouse gas emissions to 80% below 1990 levels by 2050. In the buildings sector, this will require all new buildings to be 'near zero-energy [1], in line with the requirements of the EU Energy Performance in Buildings Directive [2].

But while the components and materials needed to design and build sustainable, low-carbon buildings are widely available and often more affordable [3], only a few such buildings exist, typically showcased as one-off exemplars rather than the norm. This can be attributed in part to the lack of appropriate codes, standards and incentives [3]. But more fundamentally, the organisation of the construction industry and the relationships between different actors create a range of barriers to innovative, low-energy buildings. These barriers are harder to tackle through traditional policy measures, because they are embedded in long-standing and entrenched industrial structures and processes [4].

The objective of this review is to examine the role that SCI can play in abolishing these barriers, to conceptualise on SCI at building project level and to explore its components and underlying mechanisms towards successful delivery of sustainable, low-energy buildings. Existing literature suggests that integration is a multi-dimensional concept with many different constructs and measures [5]. Given this plurality, the paper first reviews the literature to more clearly define SCI, to identify its essential features and to establish the relationship between these features and traditional measure of project performance. Using these findings, the paper then explores the contribution of SCI to the successful delivery of sustainable, low-energy buildings. The paper therefore addresses the following research questions:

1. What are the key components of SCI in building projects and what mechanisms govern the relationship between these and traditional measures of construction performance?
2. To what extent do these or different SCI components and relationships are present in the successful delivery of sustainable, low-carbon buildings?

### 3. What are the implications of these findings for research, policy and industrial practice?

This paper is structured as follows: Section 2 introduces the concept of SCI and the rationale for industrial change, while Section 3 explains the methodological approach of the review. Section 4 provides the results of a critical and systematic review of the literature on SCI in general and in sustainable, low-carbon contexts and traces their relationship to traditional measures of building project performance. These findings are used to develop a conceptual framework for SCI. Section 5 then offers an inductive synthesis of findings across the themes of trust-based governance, integration (of systems, management, and supply chains), and outcomes. Finally, Section 6 summarises the main findings and their implications, and provides some suggestions for future research.

## 2. THE NEED FOR INDUSTRIAL CHANGE AND THE IMPORTANCE OF SUPPLY CHAINS

Traditionally, construction supply chains are highly fragmented, characterised by adversarial practices and transient rather than long-term relationships. This leads to transactional relationships, lack of trust between actors and an unwillingness to collaborate and share information [6]. The architecture, engineering, and construction (AEC) industry has long been criticised for slow rates of productivity and innovation [7]–[9] and this has been mostly attributed to its fragmented structure, which exists in three dimensions [10]:

- A. horizontally, due to the number of disciplines, trades and specialist sub-contractors involved in each stage of a building project; these are usually bound together by dyadic contractual relationships that promote split incentives barrier to communication and sharing of information;
- B. vertically, due to the separation of responsibilities between design, construction and operation within building projects that are typically arranged sequentially with appointments based on lowest price than best value; and
- C. longitudinally, with the appointment of different teams between projects, thus hindering knowledge sharing;

To partially address these concerns, architects, engineers, and construction experts—referred to here as the Architecture, Engineering, and Construction (AEC) sector— have begun to explore more collaborative ways of working and greater levels of integration throughout their various supply chains. Supply chain integration (SCI) can be defined in a number of ways, but commonly implies: *‘the merging of different disciplines and organisations with different goals, needs and*

*cultures into a cohesive and mutually supporting unit'* [11]. Efforts to improve integration have been mostly driven by a desire to improve efficiencies in project processes, so their effects were mostly measured against traditional construction management metrics, such as time, cost and defects.

The SCI concept originated within the manufacturing sector[12], where supply chains have been integrated by focal companies, usually client firms, linking and coordinating suppliers' processes to their own business processes. The underlying principle is that a supply chain that delivers a product should not comprise disconnected functions [13]. In the context of construction, integration is aimed at alleviating the effects of fragmentation and improving the effectiveness and efficiency of delivering the building product [14]. Yet, SCI faces challenges due to the project-based nature of the industry, its sub-contracting culture and the complexity and longevity of the building product that calls for high-specialisation and greater levels of risk [15], [16].

At its core, integration is associated with inter-organisational collaboration [5]. For example, within supply chain management (SCM), SCI has been defined as "the degree to which a focal company strategically collaborates with its supply chain partners and collaboratively manages intra and inter-organizational processes" [12]. Moharana et al [17] argue that integration, although closely related to the concept of "working together", is a more complex construct. They identify three terms associated with 'working together' that reflect different levels of involvement between participants, namely: cooperation, coordination and collaboration. Cooperation is defined as 'working together' based on a positive attitude towards each other, rather than a close operational relationship. Coordination denotes a more active involvement, with some interaction. Although coordination involves sending the right signals or sharing information and policies, collaboration signifies a more interactive process that results in joint decisions and activities. Integration, on the other hand, contains not only the notion of collaboration, but also of the 'unification' of separate parts, or the act of "making a whole' [17]. This 'unification' might not always be possible or desirable and therefore should be implemented selectively, to ensure a balance between diversity and homogeneity.

The UK AEC industry offers a useful example of how more collaborative ways of working have been pursued. This has involved three, closely related strategies:

(a) Integrative procurement: Construction procurement is broadly defined as a "framework within which construction is brought about, acquired or obtained" [18]. Procurement is an umbrella term that encompasses various aspects of project organisation, including contracts,

the degree and timing of involvement of different parties and reporting and communication protocols. There has been a shift towards more collaborative procurement methods, for example with Design and Build and Prime Contracting routes, where design, construction and sometimes operational management responsibilities are given to a single contracting entity. This vertically integrates the project process by minimising the number of parties involved. Another is Integrated Project Insurance, where collaborative working is targeted through aligning the interests of all team members by setting pre-determined maximum financial exposure limits for all parties;

(b) Project partnering: The promotion of openness and trust between supply chain actors has been achieved through various forms of project partnering or alliancing, defined as: "... two or more organisations working together to improve performance through agreeing mutual objectives, devising a way for resolving any disputes and committing themselves to continuous improvement, measuring progress and sharing the gains" [19]. Partnering concepts are based upon 'relational contracting' principles aimed at creating the opportunity and willingness to collaborate between supply chain actors, through long-term arrangements, shared problem solving, mutual exchange and trust [20], [21];

(c) Strategic partnering: The development of long-term relationships between supply chain actors, based on trust and commitment, has been achieved through strategic partnering. This involves long-term contractual arrangements such as framework agreements which extend partnering beyond single projects. The aim is to create "tight couplings" [22] between supply chain actors, leading to long term relationships and thus greater levels of integration beyond individual projects.

As cost-effective, low-carbon technological solutions are now widely available and as more sustainable building projects are available for examination, there is an increased interest in exploring the role of SCI strategies in delivering buildings that perform well *in-use*, particularly in relation to energy consumption and sustainability. The effective delivery of sustainable, low-energy buildings requires interaction and the seamless flow of information between different disciplines and actors. This is essential, since the greatest performance improvements arise by optimising how the different elements of a building work together, rather than relying upon individual technologies [23]. Low-energy buildings therefore require high-levels of collaboration, trust and integration - preferably extending over several building projects. SCI strategies at project level can therefore contribute in minimising environmental impacts, delivering optimal

performance during operation and be economical to run, while simultaneously minimising defects and keeping construction cost and delivery times within designated levels.

Within the large body of literature on SCI in AEC, there are many studies that demonstrate the positive impact of integration on traditional measures of project performance [24]–[27]. As the benefits of collaboration have been clearly demonstrated, the question is not whether to integrate, but rather what and how to integrate for desired outcomes. And also importantly for this paper, how to integrate for the achievement of both optimum project performance and optimum building performance.

### 3. RESEARCH DESIGN: A SYSTEMATIC AND MULTI-DISCIPLINARY REVIEW

The study comprises two parts. The first part investigates SCI in building projects and its relationship to building performance outcomes within general construction contexts. To systematize the enquiry, search terms containing the words: “construction”, “integration”, “supply chain integration”, “building construction”, “collaboration” and “project” were used to identify studies in Scopus that examined SCI in building construction. Table 1 provides details of the search terms and results. In total, this search identified 506 journal articles and conference papers. After reviewing the abstracts, only a smaller sample of these were deemed relevant and selected for detailed review. Selection of 41 papers was therefore based on the following criteria:

- (i) Discussion of SCI in the context of building projects; and
- (ii) Discussion of components of SCI and the relationship of these to performance outcomes; and/or
- (iii) Inclusion of theoretical propositions on mechanisms governing these relationships; and/or
- (iv) Empirical tests of these propositions.

After reviewing the full articles, only 26 studies (of these 41) were included in the final analysis as fully meeting the above criteria (Table 1). As the unit of analysis for the review was the building project, studies discussing SCI at the firm or industry level were excluded.

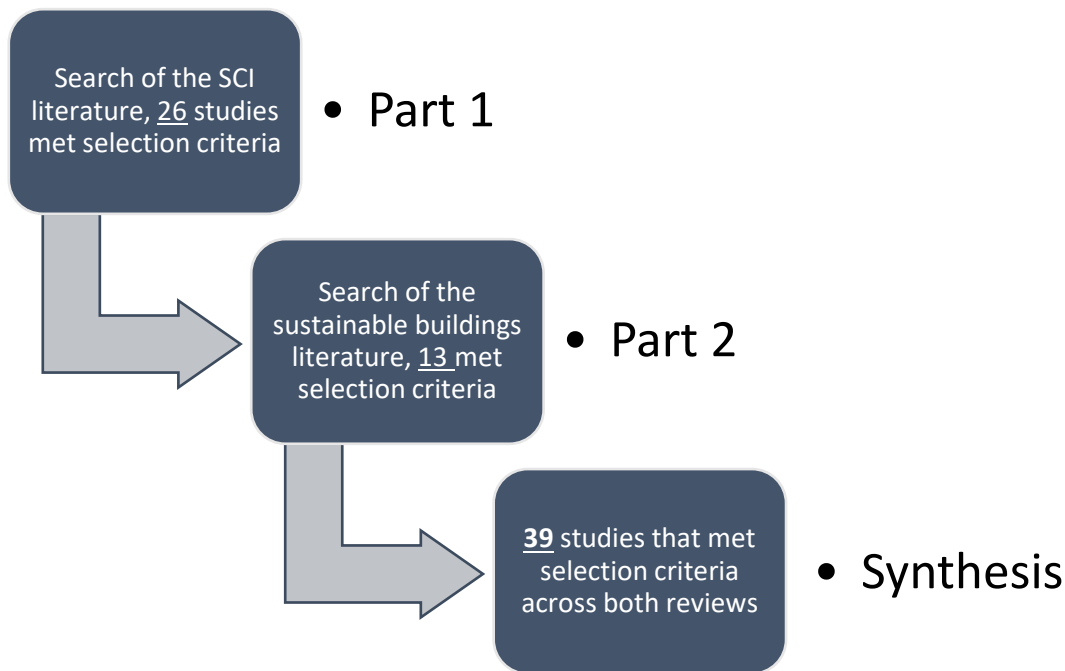
**Table 1: Search terms used in the critical review**

Initial term search	Other Filters	Overall Results	Abstract review Relevant results	Full article review Relevant results
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"supply chain integration" AND "construction"	2000 - 2017	83 journal articles and conference papers	20 journal article and conference papers	13 journal articles and conference papers
"Collaboration" AND "integration" AND "construction" AND "project"	2000 – 2017	325 journal articles and conference papers	21 journal article and conference paper	13 additional to the above journal articles and conference papers
"Integration" AND "building construction"	2000 – 2017 Engineering	98 journal articles	3 journal articles (already included above)	0 additional to the above journal articles and conference papers

The second stage of the review examines SCI components in low-energy, sustainable building literature. Again, the investigation centres on SCI in relation to performance outcomes. A manual search was considered the best strategy for Part 2, given the multiple terms used to describe sustainable buildings and SCI. This involved searching the abstracts of articles published in the 14 top journals<sup>1</sup> in buildings and construction between 2000 and 2017 (we had to end our review in 2017 due to the end of the project funding it). Abstracts were again reviewed to identify studies that: (i) addressed components of SCI in sustainable building projects; and (ii) empirically examined the relationship between these and project performance and/or building performance (e.g. sustainability or energy). This search identified only 13 journal articles that fit this description. Our approach is summarized by Figure 1.

<sup>1</sup> Defined as: *Architectural Engineering and Design Management, Building and Environment, Building Research and Information, Journal of management in Engineering, Journal of Construction Engineering and Management, Construction Innovation: Information, Process, Management, Construction Management and Economics, Engineering, Construction and Architectural Management, International Journal of Construction Education and Research, International Journal of Construction Management, Journal of Construction Research, Engineering, Construction and Architectural Management, Smart and Sustainable Built Environment, Building and Environment, Energy and Buildings.*



**Figure 1:** Summary of the two “Parts” of the systematic and critical literature reviews. Source: Authors.

Although systematic reviews have advantages over narrative reviews [28], this approach does have some limitations. The final analysis relies upon a small sample of papers selected out of a vast body of work on SCI and on sustainable buildings – so it is not claimed that this review is exhaustive. Moreover, both SCI and ‘sustainable buildings’ are ‘umbrella’ terms for multiple constructs and attributes. Exhaustive coverage would require searches of multiple alternative terms, which could increase the number of papers considered. This aside, the value of this study lies in synthesising findings from one area (SCI in construction management) to provide insights into problems and issues in another (sustainable, low-energy buildings) [28].

#### 4. RESULTS OF THE CRITICAL LITERATURE REVIEWS

##### 4.1 GENERAL AEC SECTOR (PART 1)

Within the 26 studies identified in Part 1 of the review, there are studies that investigate SCI strategies throughout the whole supply chain, from client procurement to contractor appointment and to sub-contractor and supplier involvement [29] [30]. The remainder limit the scope of their enquiry to dyadic relationships between: a) clients and contractors [31]; b) contractors and sub-contractors/suppliers [32] [33]; or c) clients and suppliers [34]. Most studies seek to qualitatively understand the integrative project process and the role that various conditions play in promoting collaborative working and integration. They typically involve case



studies, action and participatory research, which is justified considering that construction projects are not only inter-organisational, but also social settings involving complex inter-personal interactions and relationships. **Table 2** provides a summary of the 26 studies reviewed in terms of:

- (i) aspect of the project being considered in the analysis;
- (ii) component of integration considered in the analysis;
- (iii) underpinning mechanism described in the study on how integration impacts project results;
- (iv) research methods adopted in each study;
- (v) any empirical results as provided by each study.

**Table 2:** Classification of papers identified by the critical review in Part 1

No.	Paper	Project aspect considered  <i>(What to unify?)</i>	Integration components  <i>(How to unify?)</i>	Integration mechanism  <i>(Why to unify?)</i>	Research Method	Empirical results
1	<a href="#">Nicolini et al. (2000)</a> [35]	Target and whole-life <b>financial costing</b> proposed as an alternative to cost-plus method. Project costs managed collaboratively between parties.	Each project participant feeds into the costing process transparently through an open-book system and has the ability to influence the production process. No parties able to pass on risks further down the supply chain.  This set up promotes collaboratively working, and ensured cost, time and quality do not get compromised.	Early involvement of all parties – development of a single, collaboratively working team.  Exchange of information through open book costing processes thus promoting a single, transparent financial system.  Production system informed by a collectively managed costing system, thus integration between feasibility, design and construction stages of a project.	Action research  Two case study projects – both experimental.	Potential for target and whole life costing to positively affect performance, however the construction industry in the UK not yet capable of applying this at large scale due to the lack of sophisticated cost-estimation systems, and strong market orientation.
2	<a href="#">Palaneeswaran et al (2003)</a> [31]	<b>Financial costing, risk management, performance management, partner selection, innovation and conflict management</b> strategies based on relational contracting principles.	Collective agreements on objectives, fair demarcation of, and sharing of risks and responsibilities, meaningful definition of success and performance metrics, and appropriate reward/incentive arrangements.	Early involvement of parties in all aspects of project organisation.  Promotion of the ‘one-team’ concept through collaborative working processes between organisations in aspects of project organisation.  Promotion of alliance type set-ups through development of long-term relationships as in the Japanese concept of <i>Keiretsu</i> , defined as a network of businesses that own stakes in one another as a means of mutual security.	Results from a series of related case studies.	Positive relationship between cost, quality and time performance and integration supply chain, although the model proposed in the paper is not validated or tested in this study.
3	<a href="#">Bayramoglu (2001)</a> [36]	<b>Procurement method</b> – through partnering	Early involvement of all parties – before design stage commences.	As above through involvements of parties early on, this sharing risks and responsibilities and reward/incentive schemes.	Narrative review (no empirical support)	–

No.	Paper	Project aspect considered <i>(What to unify?)</i>	Integration components <i>(How to unify?)</i>	Integration mechanism <i>(Why to unify?)</i>	Research Method	Empirical results
			Contractor selection based on qualitative criteria and partnering experience, rather than on lowest bid.  Disputes resolved at the lowest level possible (e.g. worker with worker).  Sharing of risks and rewards.			
4	<a href="#">Austin et al (2002) [37]</a>	Integration of planning design and control stages.	Development and use of various design management IT tools	Develop of Integrated virtual teams to increase communication and effectiveness.	Summary of results from various research projects	Findings show need for design management tools that address changing roles within the team. IT tools contribute to better integration and performance.
5	<a href="#">Briscoe et al. (2004) [34]</a>	Integration of suppliers and sub-contractors with main contractors.	The type of client and the environmental parameters exerted on them are the most significant factor in the level of integration between construction supply chain actors i.e. suppliers, sub-contractors and main contractors.	The choice of specific procurement routes made by clients influence the way in which longer-term relationships are developed and, as a result the degree of supply chain integration between parties.	Three case study organisations with project performance parameters including level of communication, knowledge transfer, innovation and quality.	Successful project outcomes entail a clear understanding on behalf of the client of their business need. Achieving maximum integration at the earliest opportunity is essential, and clients should lead and actively promote integration.
6	<a href="#">Vrijhoef &amp; de Ridder (2005) [38]</a>	<b>Demand-side and supply-side system</b> integration in construction projects	The role of the systems integrator could be taken up by supply or demand side. Demand-side integration through clients shifting to procurement routes that promote long-term relationships and integration with their whole supply chains.  On the supply-side the role of systems integration could be developed through network building between suppliers for the delivery of products rather than delivery of projects.	Increasing the added value of projects, increasing profitability, and common socioeconomic benefits.	Two case studies	The case studies provide examples of systems integration on demand and supply side rather than provide oversight on specific positive results.
7	<a href="#">Briscoe &amp; Dainty (2005) [39]</a>	Development of integrated supply chains across projects	Through efficient management of communications, management of information flow, conflict resolution, alignment of suppliers' systems, high	Paper accepts the wider benefits of integration as prescribed within the SCI literature.	Three case studies	None of the case study projects achieved total supply chain integration and the author poses the question whether this might be

No.	Paper	Project aspect considered <i>(What to unify?)</i>	Integration components <i>(How to unify?)</i>	Integration mechanism <i>(Why to unify?)</i>	Research Method	Empirical results
			quality standards in client expectations, long-term relationships.			very difficult to be achieved given the nature of construction in UK
8	<a href="#">Cicmil &amp; Marshall (2005)</a> [40]	<b>Tendering</b> procedures	Use of two stage tendering.  [Two stage tendering is an integrative tendering approach where the bidding contractor is involved early in the project process and can feed into design and then provide costings based on the developed design].	Better project performance through integration of design and construction stages.	Single case study	The expected routines of behaviour (prescribed by two-stage tendering) do not necessarily develop over time as planned. Social and managerial interventions are needed to realise benefits of structural interventions.
9	<a href="#">Khalfan and McDermott (2006)</a> [41]	<b>Procurement</b> and supply chain organisation	Aggregation of demand and supply. Demand aggregation through bundling the present and future demands of different client organisations and putting them forward into the market to get the best price from the sub-contractors and suppliers in return of certainty of continuous workflow. Supply side aggregation through delivery of a specific 'product' rather than of a project.	Integrated procurement approaches associated with conditions of mutual dependency, integration, collaboration, goal sharing, and trust.	Two case studies	The framework agreement approach to procurement has brought substantial benefits to the two projects in terms of savings in tendering costs, time savings on programme and lessons learned for the delivery team, added value and better performance management.
10	<a href="#">Pryke &amp; Pearson (2006)</a> [42]	<b>Financial arrangements</b> in construction contracts	Pain share/gain share arrangements. Three financial incentive mechanisms investigated: activity related financial incentives, guaranteed maximum price and cluster-based incentives.	Financial incentives have the potential of increasing the effectiveness of project governance i.e. the efficient operation of contractual relationships	Three case studies of prime contracting projects.	Variation in the effectiveness of governance brought forward by the incentive mechanisms.
11	<a href="#">Khalfan et al (2008)</a> [43]	<b>Procurement</b> and supply chain organisation	Aggregation of demand and supply. Demand aggregation through bundling the present and future demands of different client organisations and putting them forward into the market to get the best price from the sub-contractors and suppliers in return of offer of continuous workflow. Supply side aggregation through delivery of a specific 'product' rather than of a project.	Integrated procurement approaches associated with conditions of mutual dependency, integration, collaboration, goal sharing, and trust.	Forthcoming case studies.	-
12	<a href="#">Ge &amp; Su (2010)</a> [6]	<b>Supply chain</b> organisation	Coordination mechanisms through trust and incentives, operational integration through organisational and information integration and IT support.	Improved performance and better relationships.	Literature review with theoretical proposition	-

No.	Paper	Project aspect considered	Integration components	Integration mechanism	Research Method	Empirical results
		<i>(What to unify?)</i>	<i>(How to unify?)</i>	<i>(Why to unify?)</i>		
13	<a href="#">Hartmann &amp; Caerteling (2010) [33]</a>	<b>Procurement</b> mechanisms for sub-contractor selection	Use of both price and trust mechanisms to govern sub-contractor procurement. Price and trust alone cannot offer optimum conditions.	More trust-based procurement procedures can abolish mistrust and adversarial relationships hence lead to better outcomes.	Choice based conjoint experiment	Both price and trust are important mechanisms in the selection of sub-contractors.
14	<a href="#">Khalfan et al. (2011) [44]</a>	<b>Procurement</b>	Partnering	Improved quality of relationships and subsequent project outcomes.	Case studies of clients	Integration of participants. at the outset of a project, can achieve effective planning and delivery of the whole project, and greater collaboration among supply chain members. Greater efforts needed to Integrate their key suppliers and manufacturers.
15	<a href="#">Khalfan et al. (2013) [45]</a>	<b>Procurement</b>	Relationships during project process	Improved quality of relationships and subsequent project outcomes.	Interviews with industry stakeholders	As above.
16	<a href="#">Manu et al. (2015) [32]</a>	Relationship between <b>contractors and sub-contractors.</b>	Trustfulness and trustworthiness (as essential qualities for SCI), change management, payment methods, economic climate, perception of future load, job performance, project specific circumstances.	A trust-based collaborative environment facilitates high levels of information sharing and secures commitments of the supply chain from the very early stages of a project.	Four case studies	Stronger and sustainable trust does not just derive from either party's demonstration of trustfulness, but on their respective trustworthiness. This is because trustfulness can also be based on the anticipated benefits or value of demonstrating a trustful attitude even when the trusted party lacks integrity and is untrustworthy. Formal control and monitoring procedures can provide the platform for parties to demonstrate their trustworthiness whilst strengthening the trusting party's trustfulness.

No.	Paper	Project aspect considered	Integration components	Integration mechanism	Research Method	Empirical results
		<i>(What to unify?)</i>	<i>(How to unify?)</i>	<i>(Why to unify?)</i>		
17	<a href="#">Koolwick et al (2015) [30]</a>	<b>Supply chain actors</b>	Strategic partnering - Extent of integrative activities, number and nature of supply chain partners and their interdependencies, duration of integration (scope), extent of involvement of higher management (depth).	There is a relation between the organizational team setting and psychological processes in collaborative construction teams. Integration contributes to positive to development of collaborative teams.	Four case studies. Action research through participatory observation.	The study finds additional elements of integration from the initial framework, such as the value of integrative activities, the size and experience of the supply chain partnering teams and the value of user involvement.
18	<a href="#">Suprpto et al (2015) [46]</a>	<b>Owner-contractor</b> relationship	Four distinct perspectives: a) shared team responsibility, b) execution focused team, c) joint capability and structure; and d) senior leadership pair.	Integration contributes to effective working relationships	30 project practitioners	An effective owner–contractor relationship should be based on affective trust, shared vision, and mutual attitudes such as open and honest communication, solution seeking instead of blaming, and senior management leadership. In contrast to prior research, long-term orientation and contractual functions were perceived to play a relatively limited role in improving owner–contractor relationships.
19	<a href="#">Mesa et al. (2016) [29]</a>	<b>Procurement</b>	Integrated project delivery procurement route (IDP)	Contractual and project organisation strategies create the drivers for supply chain relationships, which in turn influence project processes and project outcomes.	Single case study	For the case study healthcare project, the results indicate that the integrated procurement system outperformed others because its organization and contractual strategy positively impacted the drivers that define the supply chain relationships.
20	<a href="#">Poirier et al (2016) [47]</a>	<b>Procurement</b>	Inter-organisational and inter-personal collaboration	Integrated procurement enables better use or sharing of expertise throughout a project team by establishing stronger relationships and supporting more efficient and effective processes, by enabling and empowering agents to act and by offering artefacts that better support and are also better suited for use by agents within these structures and processes.	Review and theoretical paper	-

No.	Paper	Project aspect considered	Integration components	Integration mechanism	Research Method	Empirical results
		<i>(What to unify?)</i>	<i>(How to unify?)</i>	<i>(Why to unify?)</i>		
21	<a href="#">Laryea and Watermeyer (2016) [48]</a>	Procurement	Early contractor involvement, framework agreement, team's flexibility, cost-based pricing, collaborative contracts	Early contractor involvement improves performance in cost, time and quality.	Document analysis, data collection through interviews	Six conditions of success of early contractor involvement - contractor's level of experience and commitment to the arrangement, an intelligent client, existence of a framework agreement or other collaborative contracts, flexibility and openness of the designer to alternative ideas and proposals, and the use of cost-based pricing strategies.
22	<a href="#">Hosseini et al (2016) [49]</a>	Procurement	Partnering is broken down to elements such as: value-based procurement, compensation form based on open books, dispute resolution method, start-up workshops, joint objectives, follow-up workshops and early involvement of contractor	Supply chain integration through partnering achieves cost efficiency, smart building and improved quality.	Literature review and multiple case studies	Findings indicate that there is no single recipe for partnering in projects. There is no partnering element considered a must have in all projects.
23	<a href="#">Oraee et al. (2017) [50]</a>	Building Information Systems (BIM)	Collaboration in BIM network partnerships - Technology, project-related and managerial antecedents		Literature review	The study finds that collaboration has been explored singularly through the lens of technology and less through project management and people-oriented approaches.
24	<a href="#">Rahmat et al (2017) [51]</a>	Procurement	Team integration through four key determinants: commitment, collaboration through operation without boundaries and client care, no blame culture of trust and respect and experience of collective understandings.	Team integration improves project performance.	Literature review	-
25	<a href="#">Franz et al (2017) [52]</a>	Procurement	Group cohesion in team environment	Relationship between integration and improved performance.	Quantitative analysis through questionnaires of industry actors	Study finds significant correlations between the role of on-time communication in reducing construction cost overrun, higher team chemistry in reducing overall schedule growth and greater bureaucracy in increasing construction cost overruns and final unit cost.

No.	Paper	Project aspect considered <i>(What to unify?)</i>	Integration components <i>(How to unify?)</i>	Integration mechanism <i>(Why to unify?)</i>	Research Method	Empirical results
26	<a href="#">Papadonikolaki et al (2017) [53]</a>	Supply chain partnering and building information modelling (BIM)	Inter-organisational relations		Two case studies of partnerships	Contractual arrangements need to be complemented by a well-defined BIM scope, and communications across multiple tiers to build trust and support collaboration in the supply partnership network.

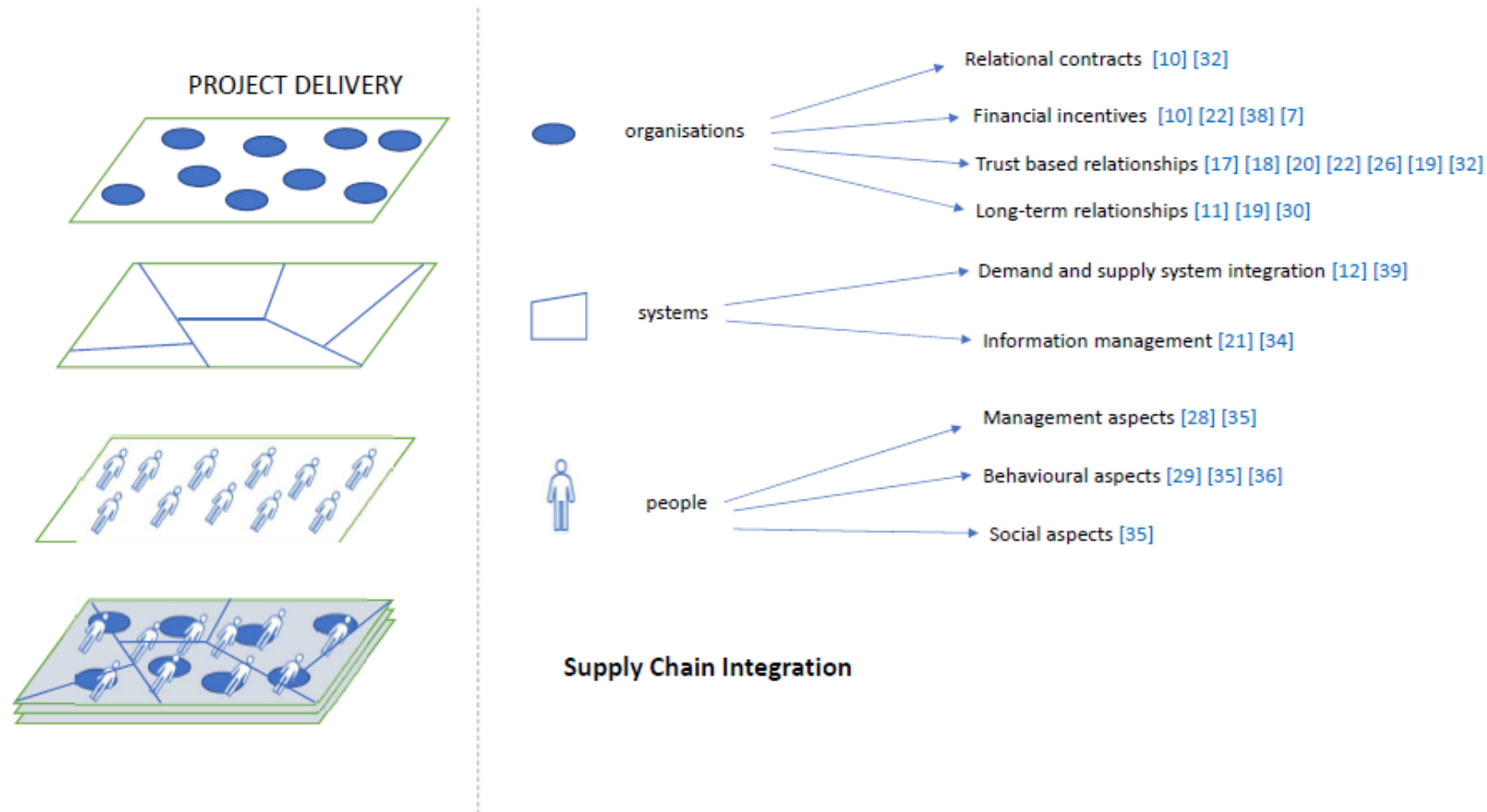


Following the review of the general AEC literature listed above, the study identified an extensive list of components of SCI in construction projects. Revisiting the concept of 'unification' introduced by Moharana et al [17] close investigation of those components indicates that SCI can be conceptualised as comprises of three layers: a) unification between supply chain firms at inter-organisational level b) unification between different project systems and c) unification between project participants at interpersonal level. This 'layering of SCI is informed by three theoretical perspectives on SCI identified in the literature, as explained below.

- (i) The inter-organisational layer, where a project is seen as a coalition of firms and organisations that need to align, collaborate and integrate. This perspective uses theoretical concepts from supply chain management (SCM), transaction cost economics and organisational theory;
- (ii) The systems layer, where a project is seen as comprising different systems that need to be coordinated to produce the required outcomes (e.g. financial system, production system, information system, demand system, supply system). To this end, systems integration in supply chains and projects relates to the roles, tools and processes that enable organisations to operate as a single entity while ensuring feedback loops between various sub-systems. This perspective uses theoretical concepts from systems theory;
- (iii) The inter-personal perspective, where a project is seen as an inter-personal and dynamic process where social interactions, behaviours and norms influence integration and outcomes. This perspective uses theoretical concepts from management studies and social psychology.

The three layers conceptual framework is provided in Figure 2.

Most of the articles included in this study address the inter-organisational layer of SCI. Under those, formal and informal governance structures are examined in relation to project outcomes. However, as noted by Rahmat (2017) [51], human oriented factors suggest the existence of identity in the individual that is not bounded by the goals and scheme of the organisation. In other words, formal and informal governance structures can create the conditions for collaboration and exchange, but this does not guarantee that collaboration will exist or that the project will be delivered successfully.



**Figure 2:** The Organizations, Systems, and People involved in Supply Chain Integration. Source: Authors.

#### 4.2 SUSTAINABLE, LOW-CARBON BUILDINGS AEC SECTOR (PART 2)

Traditionally, SCI research in AEC has been situated within the construction management discipline, while research on sustainable, low-energy buildings has been situated within the engineering and architectural disciplines. However, as cost-effective technological solutions are now available in the market and more sustainable buildings become available for examination, there are an increased number of studies focusing on project governance, organisational and behavioural aspects of projects and supply chains, addressing the need for more collaborative and integrative approaches. Industry reports indicate that the greatest potential for carbon savings in the building sector come from innovations in integrated design processes, build processes and the operational management of buildings rather than in building components and materials [3]. Advanced modelling techniques, new models of investment and leasing that minimise split of responsibilities between actors in the supply chain, off-site fabrication and better handover and commissioning practices are all encouraging systemic changes to how buildings are designed, built and operated and how supply chains are organised [3]. Improved relationships between different disciplines and trades, together with the involvement of users are essential components of greater integration both internally within the construction industry and between the construction industry and clients, such as the property and manufacturing sectors.

The following investigates how existing literature has covered the role of SCI in sustainable and low-energy buildings. Table 3 lists the 13 articles identified in the review and identifies how these address the components of the conceptual SCI model presented in Section 4 above.

**Table 3: Classification of papers identified in the critical review Part 2**

Paper	Integration aspect	Project outcome	Method	Results
<a href="#">Intrachotoo and Hsu (2003) [54]</a>	Team characteristics	Project innovation	Qualitative (8 case studies)	Environmental commitment important for successful energy efficient projects.
				Leadership role to drive sustainability goals
				Green credentials
				An alliance for testing facilities should exist.
<a href="#">Castro-Lacouture et al (2008) [55]</a>	LEED process project attributes (team integration, team exchanges, timely involvement, alignment with users/facilities).	Building performance (as built)	Quantitative	Development of a green project delivery framework.
<a href="#">Molenaar et al (2009) [56]</a>	Procurement route	Building sustainability performance (as built)	Quantitative	Integrated project delivery methods provide optimal performance.
	Tender procedures for contractor selection			Early involvement of contractor is critical.
	Contract payment method			Qualification based selection processes, produces better results.
				Success rates increase with ability to negotiate fees.
<a href="#">Swarup et al (2011) [57]</a>	Owner's commitment	Building energy and comfort performance (as built and as operated)	Qualitative (12 case studies of building projects)	High levels of integration lead to better performance under the success metric.
	Procurement route			The constructor should be on board by the design-development phase
	Team selection process	Building sustainability performance		Cost overrun characteristic of low or medium integration.

Paper	Integration aspect	Project outcome	Method	Results
	Contract clauses (inclusion of green targets, incentives and penalties)	Project performance (cost, time)		
	Methods of communication			
	Role of sustainability coordinator			
	Compatibility amongst team members			
Korkmaz et al (2011) [58]	Owner commitment	Cost performance	Mixed methods	Owner commitment, integrated procurement route, early involvement of contractor and team, long-term relationship between client and contractor, sustainability targets included in the contract contractor, use of simulation and modelling tools, regular meetings, relationships retained after project completion through collaboration with users.
	Procurement route	Quality		
	Selection of team (tender process)	Safety		
	Stringency of contract clauses	Sustainability performance (as built)		
Mollaoglu-Korkmaz et al (2013) [59]	Procurement method	Level of sustainability performance (as built)	Qualitative (12 in depth case studies)	Early involvement of contractor important to delivery of sustainable buildings.
	Selection process (tender)	Cost overrun		
	Time of involvement of participants	Quality		All procurement routes have potential to produce high-levels of integration provided there is early involvement of contractors.
	Use of collaborative management tools e.g. regular meetings and effective methods of communication			High-levels of integration occur in exemplary projects.
	Compatibility of project team members			

Paper	Integration aspect	Project outcome	Method	Results
Homayouni et al (2014) [60]	Integration strategies through:	Energy efficient/sustainable buildings (as built)	Qualitative Analysis (QCA)  Comparative  30 high-performance projects	<p>“Early &amp; Frequent Involvement of the Team members”, “Commitment &amp; Integrity of Team members”, “Advanced Implementation of BIM Technologies”, and “Setting Ambitious Environmental Objective” are necessary conditions but insufficient for creating a causal recipe for reaching higher energy efficient buildings.</p> <p>Contractual agreements do not emerge a necessary element.</p>
	Contractual agreements			
	Leadership			
	Information flow			
	Commitment and integrity of team members			
Azari and Kim (2014) [61]	Levels of integration measured as:	Building performance measured in terms of LEED Certification (As built)	Qualitative (3 case studies representing various levels of integration)	<p>Integration positively affects success.</p> <p>Sustainability performance reduces with certain contextual factors (e.g. project complexity)</p>
	Context			
	Input			
	Process			
Azari and Kim (2015) [62]	As above.	As above.	Mixed methods	As above.
Lundström et al (2016) [63]	User participation	Building performance (interior project)	Qualitative (single deep case study)	Collaboration provides a positive impact on the resulting premises.
Reed et al (2017) [64]	Integration	High-performance	Qualitative (single deep case study verifies processes and systems used)	High levels of integration lead to better sustainability performance.
				Four key stages to integration.

Paper	Integration aspect	Project outcome	Method	Results
<a href="#">Ahmad et al (2017) [65]</a>	Project delivery method (procurement)	Green Buildings as Innovative Projects	Qualitative (13 case studies)	Integrated delivery method (i.e. IPD) results in more consistent successful outcomes.
<a href="#">Holmen et al (2017) [66]</a>	Vertical integration (developer – facilities)	Product system innovation (sustainable buildings)	Qualitative (literature review and single case study)	In-house developer more able to reduce uncertainty than independent developers, as property becomes associated with lower risk after having been owned and operated.

Following the review of the sustainable, low-carbon buildings literature, the review demonstrates that integration positively influences project outcomes in both general and sustainability construction settings. But differences exist in the composition of SCI concepts between those two contexts. SCI within the context of general construction management comprises a wider spectrum of trust-based governance concepts that span beyond relationships downstream of the supply chain (client – design team – contractor) to the whole supply chain, including its upstream actors, such as sub-contractors and suppliers. Relational contracting and long-term orientation relationships between supply chain actors, as well as the timely inclusion of sub-contractors, suppliers and manufacturers are governance conditions that have not been examined in any of the studies reviewed under Part 2. This difference in the definition and operationalisation of integration between the two disciplines is discussed in Azari and Kim (2014) [61], as they describe three distinct approaches towards integration and collaboration in building construction projects:

- a. SCI, as the integration of information, agreements, leadership and processes;
- b. Integrated Design (ID), which is about integration of disciplines, information and building systems towards common goals; and
- c. Concurrent engineering (CE), which is about integration of processes and disciplines.

Interestingly, the studies included in Part 2 of this review are mostly situated within the ID group of studies, which is the predominant orientation for analysis and examination of sustainable building projects. But since sustainable and energy-saving opportunities at the system level are substantially greater than at component level, sustainable, low-energy buildings rely on an optimisation process where designers, contractors and users fine-tune components for optimum performance. Given the discontinuous nature of project-based construction, suppliers and manufacturers are therefore valuable actors as they are interested in learning between projects. For these reasons, long-term relationships between construction and other sectors, such as manufacturing, are also critical.

Part 2 articles incorporate ‘as design’ performance metrics, rather than actual performance, which although understandable given the challenges of data collection, excludes optimisation during operation as an aspect of performance. Perhaps as a result of this, the involvement of users is not given prominence in these studies. On the other hand, some additional governance conditions emerge from the analysis of sustainable projects, such as client/owner commitment



towards sustainability goals and setting of stringent project targets that are included in contractual clauses.

Most of the sustainable building studies employ qualitative research methods, although several employ combine quantitative and qualitative methods. Some of the studies [59], [67] note the challenges of collecting construction project delivery data (e.g. procurement method details). In effect, it is difficult to detect variations in delivery methods at organisational and team level using quantitative methods, and this, coupled with the limited number of completed sustainable, low-energy buildings, limits access to large sample sizes. On the other hand, attributes of project delivery, such as team dynamics, interactions and decision-making processes are not recorded and are difficult to extract when projects teams are dismantled upon completion.

Almost all the studies originate from the United States (US) and this can possibly be attributed to the existence of Leadership in Energy and Environmental Design (LEED) building assessment scheme that provides a platform for information exchange on environmental performance and project details of assessed buildings. While similar assessment schemes exist in the UK, and LEED is used globally to assess buildings, none of the studies under Part 2 of this review originate from the UK and Europe. Finally, there is a lack of studies that employ deep case studies, ethnographic and participatory research designs that are suitable for exploring dynamic interactions and relationships between different supply chain actors within the project and beyond into contextual and environmental settings.

## 5. DISCUSSION: TRUST, INTEGRATION AND OUTCOMES IN LOW-CARBON BUILDINGS

Fortuitously, the gaps and shortcomings identified by the review also point the way towards conceptual integration that each helps address some of the challenges inherent in relying on AEC or SCI approaches by themselves in isolation. The detailed results of the analysis are provided in Table 4 below. This section inductively organizes our insights into three dimensions: trust, integration, and outcomes.

### 5.1 Trust based governance

First, in terms of *trust*, in the **SCI literature** trust-based governance relates to the client's decisions on procurement routes and the contractual arrangements between supply chain actors. Two main governance mechanisms are discussed in the literature [33]:

a) *price*: whereby contracting parties are legally bounded by formal contracts and assignment of projects is undertaken through competitive tendering under market rules.

b) *trust*: whereby procurement decisions are based on collaborative approaches oriented around the establishment of long-term relationships between contracting parties. The literature identifies several trust-based governance conditions including:

- (1) Long-term relationships between contracting parties [39] [34]
- (2) Early involvement of contractors/sub-contractors/suppliers [49] [35] [68]
- (3) Costing methods that combat adversarial relationships, such as open-book accounting and target and whole life costing; [35] [34]
- (4) Relational, informal contracts [31] [49]
- (5) Where formal contracts are used, existence of collaborative contractual clauses with embedded provision for incentives [46]
- (6) Integrated procurement routes that minimise the number of participants in the project [34] [43]
- (7) Non-competitive tendering procedures that are based on value criteria rather than just price [34] [40].
- (8) Conflict resolution and change management mechanisms [30]
- (9) Compensation mechanisms that include incentives based on group performance [49] [32]

Long-term approaches promote greater levels of trust between parties and lead to better relationships, more collaboration and improved project performance [33] [45] [52]. However, Hartmann & Caerteling (2010) [33] find that price-based and trust-based procurement work best in combination, rather than as alternatives. Similarly, Palaneeswaran et al (2003) [31], find that, while dedicated involvement is essential for relational contracting, suitable monitoring mechanisms should also be installed, like in traditional ‘transactional’ contracting.

In the **sustainable buildings literature**, ten of the 13 studies reviewed addressed governance conditions of procurement and contracts. Trust-based governance is identified as an integration antecedent in sustainable building settings, as exemplified by the following conditions:

- (i) Integrated procurement routes, such as DB or IDP, facilitate greater levels of integration. Higher levels of integration deliver consistently better results in terms of sustainability performance [65], while exemplary buildings are usually delivered through integrated approaches [56] [57] [59].

- (ii) Selection of contractors and sub-contractors on the basis of qualifications or best value, rather than price, are considered more conducive to integration and better outcomes; [56]
- (iii) Negotiated rather than lump-sum methods of payment of contractors foster better relationships and integration; [56].
- (iv) Almost all the 10 studies indicate early involvement of contractors as critical to integration, project and sustainability performance, although the need for early involvement is not extended to sub-contractors and suppliers;
- (v) Inclusion of sustainability targets in contractual clauses [60].

Long-term relationships between contracting parties is not widely explored in the reviewed papers. Notwithstanding, Korkmaz et al (2011) [58] indicate 'sole-source selection' as the best option for selecting contractors, which is based on establishing long-term relationships rather than competitive tendering. Similarly, the use of more relational forms of contract in sustainability contexts is also not addressed by any of the studies.

Interestingly, studies indicate that although integration contributes to better outcomes, sustainable buildings can be delivered by all types of procurement methods and a wide range of contractual arrangements. Homayoumi et al (2014) [60] finds that lack of integrative contractual arrangements can be overcome with leadership, information systems, and work processes that engender an environment of trust, openness, and ambitiousness. Similarly, Mollaoglou et al [59] finds that all procurement routes have potential to produce high-levels of integration provided there is early involvement of contractors.

## 5.2 Systems, management, and supply chain integration

In the **SCI literature**, *systems integration* views a project as many different systems that need to be coordinated to achieve a specific outcome. Under systems theory, there are two aspects that are of importance for supply chains: synergy and entropy. Synergy relates to the parts of a system that work together to deliver more than could be achieved by working separately. Entropy refers to the necessity of feedback across the chain to prevent weakening of the system (Vrijhoef and de Ridder, 2005) [38]. To this effect, systems integration in supply chains and projects relates to the roles, tools and processes that enable organisations to operate a single entity, while ensuring feedbacks between different sub-systems.

Systems integration ensures that there is information and knowledge flow between all parties in the supply chain. The use of tools such as Building Information Modelling (BIM), increases the flow of information between participants [6], thereby helping to facilitate integration, develop relationships and build trust [34]. Integration may also require a 'systems integrator' on both the demand and supply side [38]. For example, clients could take up the role of demand integrator, while the main contractor could take up the role of supply integrator. Briscoe and Dainty (2005) [39] focus on information flows between client and supply chain and the need for supply chain actors to align their practices with clients' needs.

In the **sustainable buildings literature**, there is clear recognition among studies that governance conditions are not sufficient to deliver better outcomes in sustainable and low-energy building projects. Azari and Kim (2014) [61] argue that whereas collaboration and free exchange of information are widely mentioned in discussions around integration, "integration thinking," or "systems thinking," which refers to considering the relationships among the constituent subsystems of a system in order to create an optimized performance seems to be less explicitly examined. In systems thinking, any decision making on the subsystem of interest must be made by involving all disciplines, as representatives of subsystems, in the decision-making process [49].

Building Information Modelling (BIM) and advanced energy modelling is considered by Homayouni et al (2014) [60] and Korkmaz et al (2011) [67] as a necessary condition for better sustainability outcomes. Reed (2017) [64] argue that simulation tools are essential for delivering sustainable buildings because a high- performing building can only be achieved through integrated building systems. These in turn require an integrated team with the right people, and integrated information to function effectively and efficiently.

The role of the systems integrator is not directly covered in the reviewed literature. However, several studies identify the need for the existence of sustainability leadership roles and the importance of the role of the client. Azari and Kim (2014) [61] find that "green achievement" is a client-driven pursuit that needs to be introduced early and communicated to all participants.

Finally, the role of users is identified as important in the delivery of optimised sustainability performance. Integrating users within the project process as well as the need to integrate facilities within construction supply chains is addressed [55], [63], [66].

In terms of *integrated management*, in the SCI literature trust-based governance and systems integration can foster environments where integration and collaboration can exist, but these

may not always materialize because projects are also social settings with complex relationships between individuals.

Integrated management antecedents relate to on-going management practices aimed at increasing collaboration, trust and social interactions at an interpersonal level. Such antecedents may include recurring follow-up meetings making partners perform in a common direction, the existence of a joint project office that enhances face-to-face communication and teambuilding activities that involve socialization of partners [30] [62].

Integrated management antecedents are not however limited to pre-determined practices and actions as the previous two groups of antecedents. Cicmil (2005) [40] investigates what would form 'adequate social and managerial intervention' in construction projects to overcome the limitations of governance interventions. The study develops a framework for understanding complexity in construction projects and the implications of this for management practices: *"in an unpredictable world where the outcomes of an action cannot be known in advance, managing should be seen as a process of continually rearranging the paradoxes of organizational life through a different type of leadership"*. Suggested skills include ongoing processes of renegotiation and redefinition of goals and future joint action, reflexive understanding of one's own role in processes and an ability to introduce change.

In the sustainable buildings' literature, several studies address integration conditions at an interpersonal level. For example, Mollaoglou et al (2013) [59] find that chemistry among participants can affect integration through the comfort/discomfort arising from participants' past experiences of working with each other and on the type of facility in question. The study finds that a thorough selection process should be conducted not only to ensure the qualifications and capabilities of the participants, but also to align their commitment to the project and to its environmental objectives, to avoid team compatibility issues. Similarly, Homayoumi et al (2014) [60] finds that the commitment and integrity of team members is one of the necessary conditions for better performance outcomes in sustainable building projects.

In terms of *supply chain integration*, the following attributes have been described by the SCI literature to comprise integration in project processes

- Working together, mutual respect, direct relationships between disciplines and better understanding of each other's' remit and capabilities.

- Development and existence of mutual trust and respect, transparency and effective communications.
- Information flow and systems and communication, information, co-ordination, commitment, collaboration
- Collaboration and commitment flow of information.
- Improved coordination
- Alignment of interest and objectives, Gain and pain sharing, Trust, No-blame culture, Team working,
- Communication, Conflict resolution, Continuous improvement
- Trust (Truthfulness and trustworthiness)

In the sustainable buildings' literature, the following attributes have been identified to describe the process of integration in sustainability projects [49]:

- Accountability
- Commitment
- Communication
- Compatibility
- Timely involvement
- Joint operations
- Mutual respect

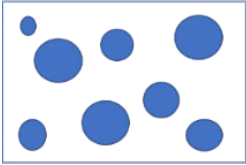
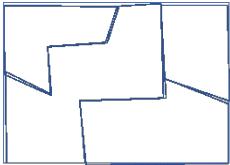
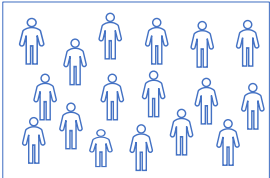
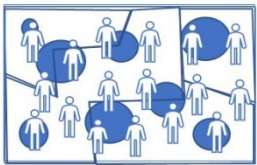
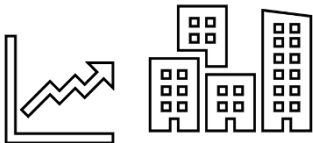
### 5.3 Outcomes

Last but not least, in terms of *outcomes*, in the **SCI literature** governance, systems integration and integrated management are envisioned as antecedents in combination with contextual and environmental factors lead to the integrative project process, which in turn leads to positive performance outcomes. As most studies comprised qualitative methods of analysis, it is not possible to identify causal recipes towards better outcomes. Furthermore, none of the studies indicate a hierarchy between the four antecedents of SCI. All the SCI studies reviewed in this study examined project performance outcomes, rather than building performance outcomes.

In the **sustainable buildings literature**, performance metrics vary significantly between the analyses. LEED level of certification prevails [58] as the most common dependent variable, however in some studies, combinatorial variables are constructed to evaluate the energy and/or comfort dimensions of sustainable, low-energy projects [59]. Four studies include project

performance in their dependent variable, based on the position that sustainable, low-energy buildings should be delivered in successful projects [57], [64]. All but one of the studies [57] include “as designed”, rather than “as operated” performance metrics. All studies identified integration as positively affecting as built sustainability performance.

**Table 4: Synthesizing integration components in the SCI and sustainable buildings literatures**

Integration component	SCI literature	Sustainable Buildings literature
Trust-based governance 	Relates to the client’s decisions on procurement routes and the contractual arrangements between supply chain actors, and often centres on price and trust	Relates more to conditions of procurement and contracts, and the involvement of contractors in procurement decisions
Systems integration 	Seeks to achieve synergy and avoid entropy in supply chains	Seeks to achieve sustainability leadership roles and the importance of the role of the client
Interpersonal level integration 	Emphasizes fostering environments where integration and collaboration can coexist	Emphasizes integration conditions at more interpersonal levels
Supply Chain Integration (Process) 	Focuses on making project processes more aligned, efficient and transparent .	Focuses on making project processes more aligned, coordinated, and client-led. compatible
Outcomes 	Tends to examine project performance outcomes rather than building performance outcomes	Tends to examine building performance outcomes rather than project performance outcomes

## 6. CONCLUSIONS

This study has developed an enhanced conceptual framework for SCI in building projects. The model identifies four key antecedents to SCI, namely trust-based governance, systems integration, integrated management and external enabling factors. Each antecedent category includes a large number of conditions that can be implemented in projects and lead to greater levels of integration and project performance. The model proposes that the interplay between these conditions promotes more integrated supply chains and improved project outcomes. The existence of trust-based governance between contracting parties creates the conditions for collaboration to exist and develop. But collaboration cannot exist without the integrated flow of information and coordination between the different project systems towards common project outcomes. And collaboration cannot be successful without a common culture and interpersonal chemistry between participants, supported and sustained by integrated management practices.

A holistic appreciation of SCI is needed if its benefits are to be realised at wider scales within the AEC industry, and particularly for the delivery of sustainable buildings. In those contexts the interplay between the three layers of integration are widely recognised, but possibly not adequately researched (academia), applied (industry) and facilitated (policy). Due to the difficulties in collecting data on project characteristics, supply chain structures and the relationships between different actors, relatively few studies have explored this interplay and how it contributes to building and project performance. The use of methods that employ deep case studies, ethnographic and participatory research designs are more suitable for exploring such dynamic interactions and relationships between different supply chain actors within the project and beyond into contextual and environmental attributes.

The following concluding recommendations stem from the findings of this paper and represent areas where further research would need to be undertaken:

For academic research, focus should shift from production to 'in-use' performance, which identifies user-involvement as critical for achieving energy system optimisation and reduced emissions in buildings. The model should therefore be expanded to include antecedents that focus on integration between supply chain and user interfaces, such as facilities managers, and occupiers. There needs to be inclusion of upstream parts of a building supply chain (i.e. sub-contractors, suppliers and manufacturers). It is not only project performance that is of interest, but the combined outcome of project and building performance and further research could be



focusing on both of those performance dimensions. A UK perspective is missing and should become available through further research exemplifying the conditions prevailing in the sector. There is a need for analysis of governance antecedents beyond the level of procurement methods, onto finer-grade governance conditions, such as contractual clauses, long-term relationships, supply chain actor's relationships beyond project team level. There is a need to understand the dynamic and on-going integrative processes, where social theory and behavioural aspects can contribute in the analysis.

For industry and national policy development, systematic collection of data relating to soft parameters of projects, such as procurement arrangements and their rational, contracting arrangements, team integration and coordination processes etc. Exploration of client roles and how client capabilities can be enriched in order to drive green buildings. Identification and further qualification of the role of the systems integrator in sustainability projects. There is also a need to identify optimum roles for the different types of client in sustainability projects. Acknowledgment that procurement strategies would benefit from adopting all three layers of integration. As optimised building performance does not necessarily imply subsequent project performance benefits in terms of cost and time, legislation and industry standards are needed to drive demand for such buildings.

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